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Prediction of Wind Energy Distribution in Complex Terrain using CFD

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ABSTRACT

Based on linear models, WAsP software predicts wind energy distribution, with a good accuracy for flat terrain, but with a large error under complicated topography. In this paper, numerical simulations are carried out using the FLUENT software on a mesh generated by the GAMBIT and ARGIS software to predict wind speed distribution in complex terrain. TECPLOT software post-processing is used to get the whole wind flow field, the wind speed distribution characteristics and distribution of wind energy. The obtained results are compared with the results of WAsP software and are also more accordance with the actual conditions.

Keywords: wind farm, complex terrain, wind energy resources evaluation, CFD numerical simulation

0 INTRODUCTION

In recent years, wind energy has become the fastest growing renewable energy [1-3]. Wind energy resource assessment is a basic work for the construction of wind farms. Power calculation of a wind farm is directly related to economic factor and wind power grid connection. Currently, wind energy resource and power capacity are usually calculated by WAsP software developed by Danish RisΦ laboratory. The linear model was adopted in the software.Wind energy resource assessment and wind power output are often accurate for the flat terrain and would be higher error for the complex terrain. The software should be further improved for increasing the prediction accuracy [4-5]. With the wind energy resource exploitation further development, wind farm site is transferring from flat terrain of wind speed stability and good construction conditions to complex terrain of high turbulence and bad construction conditions [6-8]. So it is essential to develop a novel method or code to estimate the wind energy distribution or the wind farm layout.

Due to the complex topography, wind energy distribution and turbine output calculations are difficult currently because of the aerodynamic detouring flow and the turbine wake models, and the former is usually the key point. At present wind mast data are very too limited to estimate the whole wind farm energy distribution accurately. With rapid development of CFD technology in recent years, many researchers tried to apply the technology to estimate the wind energy for the wind farm [9-13]. This paper tried to develop a numerical calculation method by combining the topography data process, CFD model and calculation, post-processing. Through the calculation analysis of wind speed and wind energy distribution of a wind farm, the results obtained are compared to the results of WAsP software and it could show the more accordance with the actual conditions. At the same time the method developed by the paper is easy to apply to the actual engineering.

1 TERRAIN DIGITAL PROCESSING

Complex terrain of a wind farm is usually depicted by Autocad isohypse contour, But when calculating aerodynamic field by CFD, it needs to digitize the complex terrain for developing the physical model. Argis is a powerful software which can analysis geographic information system, digital map, geographic information acquisition, and is also the most powerful and the most widely used in geographic information system industry. This paper uses the Argis to get tin file by separating contour figure of Autocad file, and the tin file can be turned into dem file of coordinates by discretization. In this paper, the wind farm calculated is from north China. The original Autocad isohypse contour is shown in figure 1, and the terrain discreted is shown in figure 2 by the Argis software. Figure 3 is the wind farm contour map, which is fitted to the results obtained by Argis at height. By the comparison and analysis, the topographic map discreted by ARGIS software is in accordance with the original digital topographic map with very high accuracy.

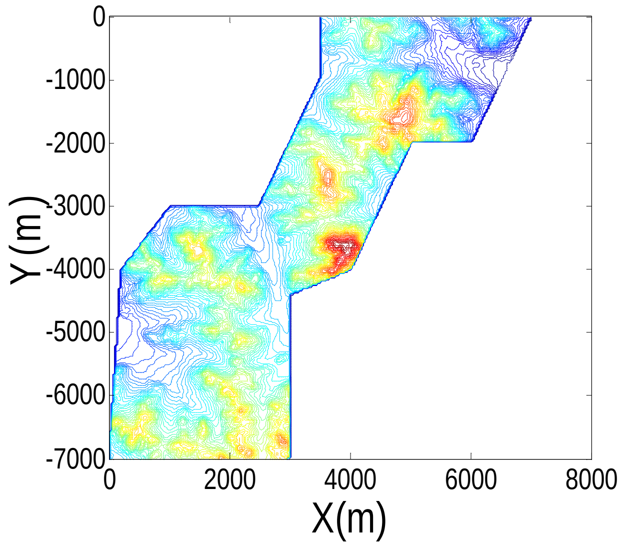

Figure 1: Two-dimensional Autocad terrain isohypse contour

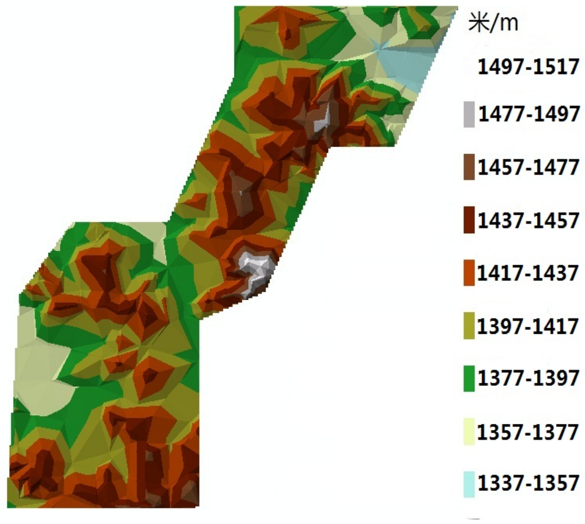

Figure 2: Argis map

According to the complex topography and discreted digital files, develop the physical model of topography in the Gambit software. According to the topographic data, the selection of calculation area is 7000 m * 7000 m * 500 m, the blank terrain in original map complemented by surrounding terrain ,as shown in figure 4, The height is 500 m, choose the unstructured grid, ground surface grid for 30 m by 30 m, In the vertical direction on the surface to mesh with 500 m height is divided into three layers, 0 to 50 m, 50-200 m, 200-500 m respectively, and the grid interval is 5 m, 10 m and 30 m respectively .

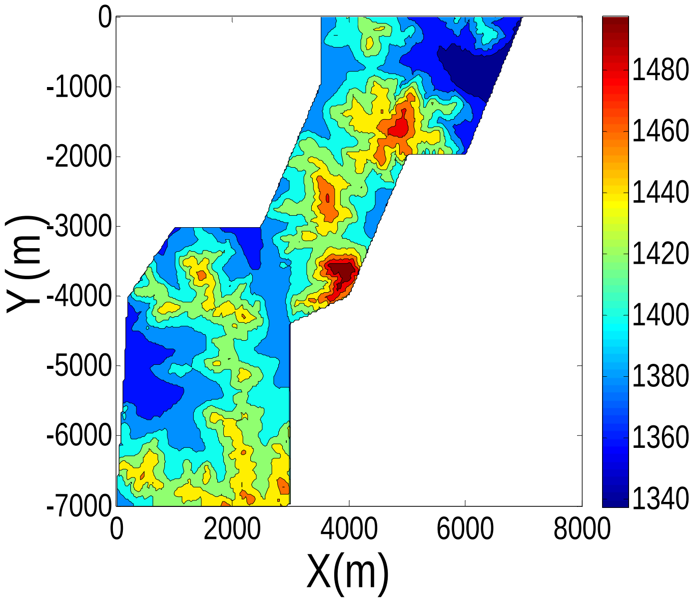

Figure 3: Wind farms contour map

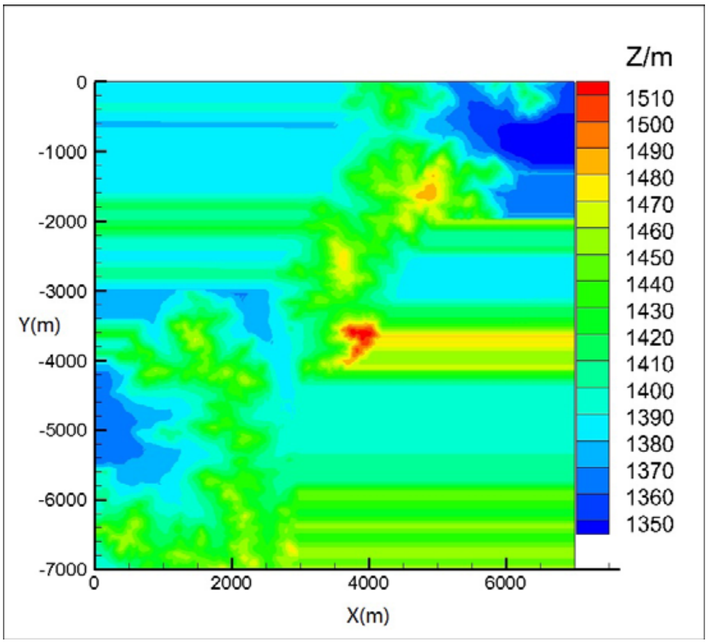

Figure 4: Wind farm calculation zone

2 MATHEMATICAL MODEL AND CALCULATION

Standard Navier - Stokes equations (cartesian coordinate system) are expressed as equations (1)-(4) [14]:

$$\frac{\partial \rho}{\partial t} + div(\rho \vec{u}) = 0 \tag{1}$$

$$\rho \frac{\partial u}{\partial t} + div(\rho u \vec{u}) = div(\mu \, grad \, u) - \frac{\partial p}{\partial x} \tag{2}$$

$$\rho \frac{\partial v}{\partial t} + div(\rho v \vec{u}) = div(\mu \, grad \, v) - \frac{\partial p}{\partial y} \tag{3}$$

$$\rho \frac{\partial w}{\partial t} + div(\rho w \vec{u}) = div(\mu \, grad \, w) - \frac{\partial p}{\partial z} \tag{4}$$

This article chooses the steady, constant physical property control equations and the standard k - ε turbulence models are used [15] :

$$\frac{\partial \rho k}{\partial t} + div(\rho k \vec{u}) = div(\Gamma_k \, grad \, k) + G - \rho\varepsilon \quad (5)$$

$$\frac{\partial \rho k}{\partial t} + div(\rho \varepsilon \vec{u}) = div(\Gamma_k \, grad \, \varepsilon) + \frac{C_{1\varepsilon}}{k} G - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} \quad (6)$$

ρ is the density of air, and u , v the horizontal wind speeds respectively, w the vertical wind speed, p the air pressure, μ the turbulence viscosity, Γ_k diffusion coefficient of k , G the turbulent energy generation rate or the kinetic energy dissipation rate, $G - \rho\varepsilon$ the net source term and the model constant. Equation parameters are set as: second order discretization form of the upper wind method, bottom boundary conditions are processed with the wall function method, entrance is velocity inlet, outlet is outflow, others are all symmetry conditions. Equations are solved by the simplic algorithm. According to the wind speeds from the wind masts in the wind farm. Wind rose diagram is divided by 12 sections, the average wind speeds of each section are calculated. And the boundary condition is used by equation (7):

$$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right) \quad (7)$$

u_* is speed of surface friction coefficient, κ is the von Karman constant (0.4), z_0 is surface roughness length . Inlet boundary condition is coupled by Fluent UDF editor. Wind velocity inlet of 0 to 30^0 direction is shown as Figure 5, it can be seen the trend of velocity inlet increases along the height direction. The ground wind speed is close to zero.

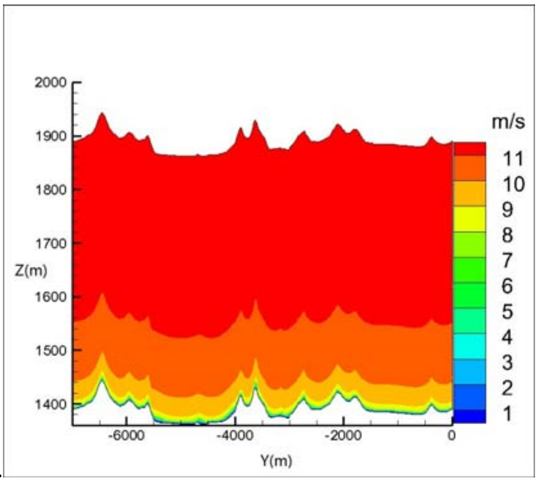

Figure 5: speed inlet condition from 0 to 30 degree

3 RESULT ANALYSIS

3.1 Wind calculation results

Wind energy density is defined as wind energy power per area [16], Thus wind energy density formula, also called wind power density formula is expressed as:

$$w = \frac{1}{2} \rho v^3 \quad (8)$$

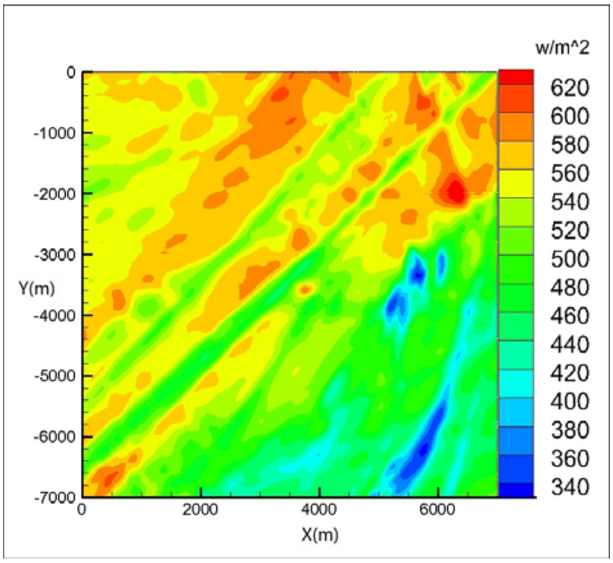

Figure 6: Wind energy distribution (z=1600m)

Aerodynamic field computations are carried out by FLUENT software in 12 directions. Wind energy distributions are summerized according to wind speed probability distribution of each direction by TECPLOT software. Wind energy distribution is shown as from Figure 6 to Figure 8 at different heights. Wind energy distribution will increase with height increasing. But there is very big difference at the same height level because of different height and detouring flow. Figure 9 and Figure 10 show the local wind energy distribution and velocity distribution at the position of the topographic map, which the specific scope of coordinates is x = 2500-5000 m and y = - 3000 m. In Figure 9, the wind energy distribution is obtained from 12 wind speeds due to probability distribution, Figure 10 is the wind velocity distribution when the wind blowing hillside at the wind direction of 0 to 30 degree zone, which can be seen from the figure leeward slope wind velocity is smaller than windward slope wind velocity, the wind speed decreases caused by slope block as a result of the energy loss.

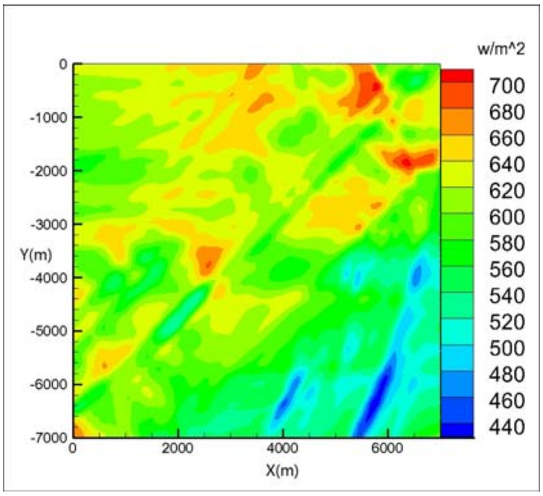

Figure 7: Wind energy distribution (z=1700m)

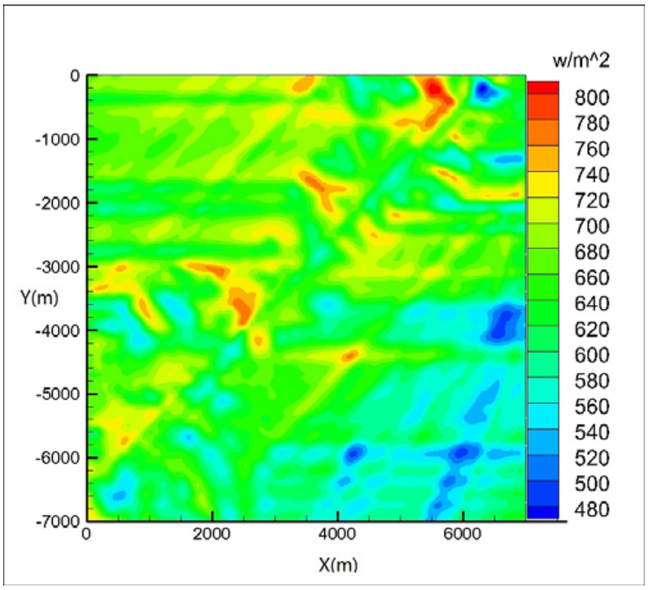

Figure 8: Wind energy distribution (z=1800m)

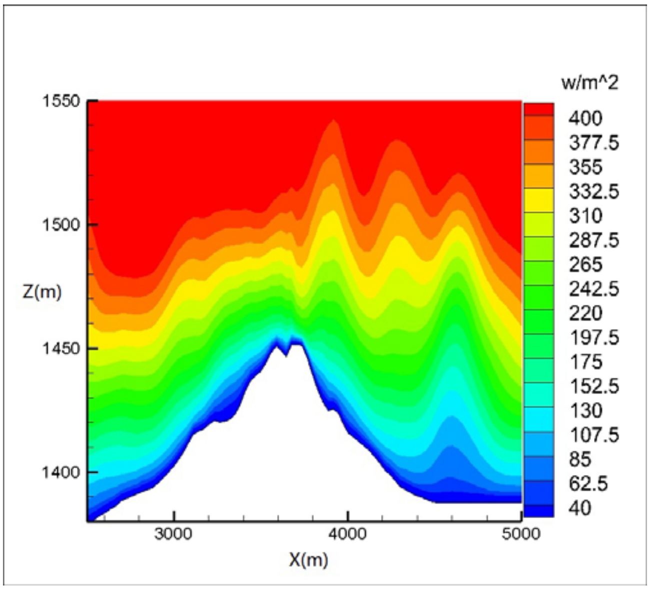

Figure 9: Local wind energy distribution

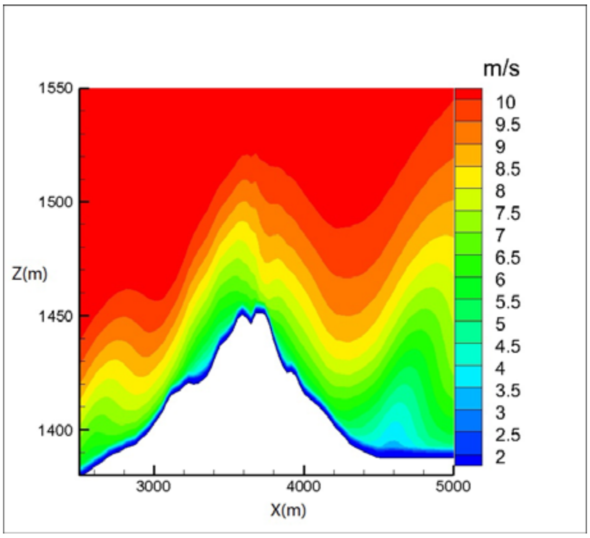

Figure 10: Local wind velocity distribution

3.2 Comparison between numerical simulation and WAsP software

In the CFD calculation result of the wind farm, along the prevailing wind direction, 20 evenly distribution points are checked by the results of the CFD numerical simulation and the WAsP software respectively. Results show that there are some differences between these two methods. In the Tab.1, points from 6 to 20 , CFD results are smaller around 100-200 w/m^2 than the results of the WAsP, and the first five points is close to the edge of the terrain, the result of range is bigger. From Figure 11,we can intuitively see, just the second calculation point in the distribution of wind energy outweighs the WAsP. The other CFD calculation results are less than the WAsP calculation results. The calculation results are consistent with the engineering results, which wind distribution calculated in complex terrain using WAsP is often bigger than the measurement from the wind farm at present. This is because the WAsP is just taking consideration of the height influence on the wind speed by Lissaman model, while ignoring the detouring flow of the terrain. Otherwise, CFD numerical simulation method takes the terrain height and detouring flow effect on wind speed distribution, thus more accord with the actual wind power distribution results obtained.

Tab.1 distribution of wind energy in 20 calculated point by CFD and WAsP

Points	X/m	Ym/	Z/m	CFD/ (w/m^2)	WAsP/ (w/m^2)	Difference/ (w/m^2)
1	150. 8621	-6849. 14	1428. 775	352. 0798	378. 3076	26. 2278
2	452. 5862	-6547. 41	1487. 5	568. 931	432. 9725	-135. 9585
3	754. 3103	-6245. 69	1459. 047	394. 0908	412. 5912	18. 5004
4	1056. 034	-5943. 97	1415. 502	214. 5136	354. 0609	139. 5473
5	1357. 759	-5642. 24	1428. 367	319. 9514	377. 6848	57. 7334
6	1659. 483	-5340. 52	1419. 449	215. 2356	362. 272	147. 0364
7	1961. 207	-5038. 79	1447. 859	270. 9516	402. 0661	131. 1145
8	2262. 931	-4737. 07	1434. 054	195. 2646	385. 8512	190. 5866
9	2564. 655	-4435. 34	1438. 466	246. 8089	391. 5182	144. 7093
10	2866. 379	-4133. 62	1419. 913	149. 0633	363. 1724	214. 1091
11	3168. 103	-3831. 9	1435. 779	163. 1859	388. 1296	224. 9437
12	3469. 828	-3530. 17	1480. 485	271. 2416	428. 591	157. 3494
13	3771. 552	-3228. 45	1455. 358	220. 3219	409. 3249	189. 003
14	4073. 276	-2926. 72	1452. 328	235. 1058	406. 4986	171. 3928
15	4375	-2625	1441. 018	205. 4146	394. 5711	189. 1565
16	4676. 724	-2323. 28	1459. 547	265. 2732	413. 0201	147. 7469
17	4978. 448	-2021. 55	1482. 582	293. 8114	429. 9375	136. 1261
18	5280. 172	-1719. 83	1477. 5	316. 9961	426. 6165	109. 6204
19	5581. 897	-1418. 1	1433. 579	194. 8793	385. 2088	190. 3295
20	5883. 621	-1116. 38	1415. 281	254. 5544	353. 5692	99. 0148

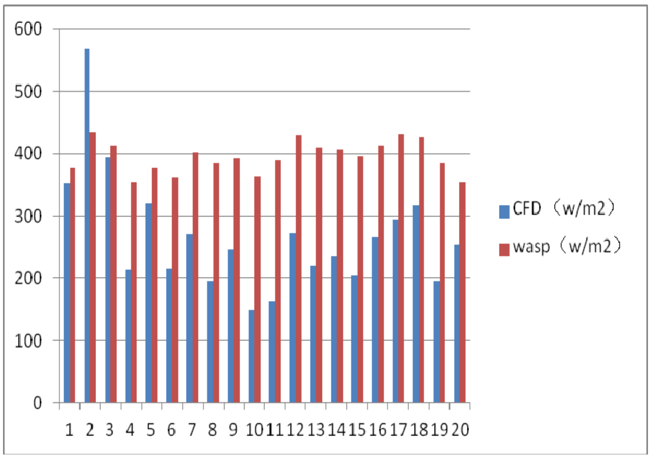

Figure 11: Wind energy diagram in calculation 20 points by CFD and WAsP

4 CONCLUSIONS

(1) In the complex terrain, it was compared that the wind power distribution calculation results of the CFD and the WAsP software, and CFD calculation method calculates more accurately the wind flow over the complicated topography and the distribution of wind energy.

(2) WAsP is a traditional wind resource evaluation software based on the linear wake model and Lissaman model. Calculation error is often a little big for complex terrain. CFD numerical simulation method for complex terrain can take the effects of wind speed change with height by detouring flow accurately, the wind energy calculation results are often smaller than the results of WAsP. This matches the fact that WAsP calculation results are often over-estimated in complex terrain.

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